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SILAGE

densities and losses as found in

LABORATORY SILOS

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SILAGE DENSITIES AND LOSSES AS FOUND IN LABORATORY SILOS

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Widespread interest in use of meadow crops since 1935 focuses attention on the problems of silage pressures and juice loss. When farm silos are emptied a quantitative accounting of all the material weighed in the silo is extremely difficult. Many research workers have studied this problem and most agree that an 8 to 10 percent loss is unavoidable. To study the ensiling process, investigators have used milk bottles, fruit jars, crocks, plastic bags, barrels, large tiles, boiler sections, and small silos holding 2,000 to 2,500 pounds. Resulting silages are seldom found to be of a quality comparable to that obtained from the same material ensiled in farm-sized silos. Even in the larger experimental silos the exclusion of air usually is not sufficiently complete to facilitate desirable fermentation.

The weights of material overlying a square foot of surface may be calculated for different depths, but the sum of those weights is not the pressure at that level.

EQUIPMENT AND PROCEDURE

A silo holding approximately nine pounds has been developed and described elsewhere.[2] In its earliest form, (Fig. 1)[3], it consisted of an 18-inch section of six-inch steel pipe screwed into a pipe flange, mounted on a solid wood base. After the crop is packed into the cylinder, the suspended platform and plunger are then put in position and the specified amount of weight is placed on the platform.

Any expressed juice is collected in the fruit jar which is attached to the base through the screw cap of the jar. Because of rusting walls this silo was not entirely satisfactory. Pyrex glass cylinders with glass jars

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[1]Now retired.

[2]A. E. Perkins and A. D. Pratt. A Laboratory Silo and Its Uses. Jour. of Dairy Sci., 34: 606-614, 1950.

[3]Acknowledgment for this drawing and for cooperation in filling these silos is gratefully made to W. A. Junnila, now of the University of Connecticut, cooperating with the U.S.D.A.

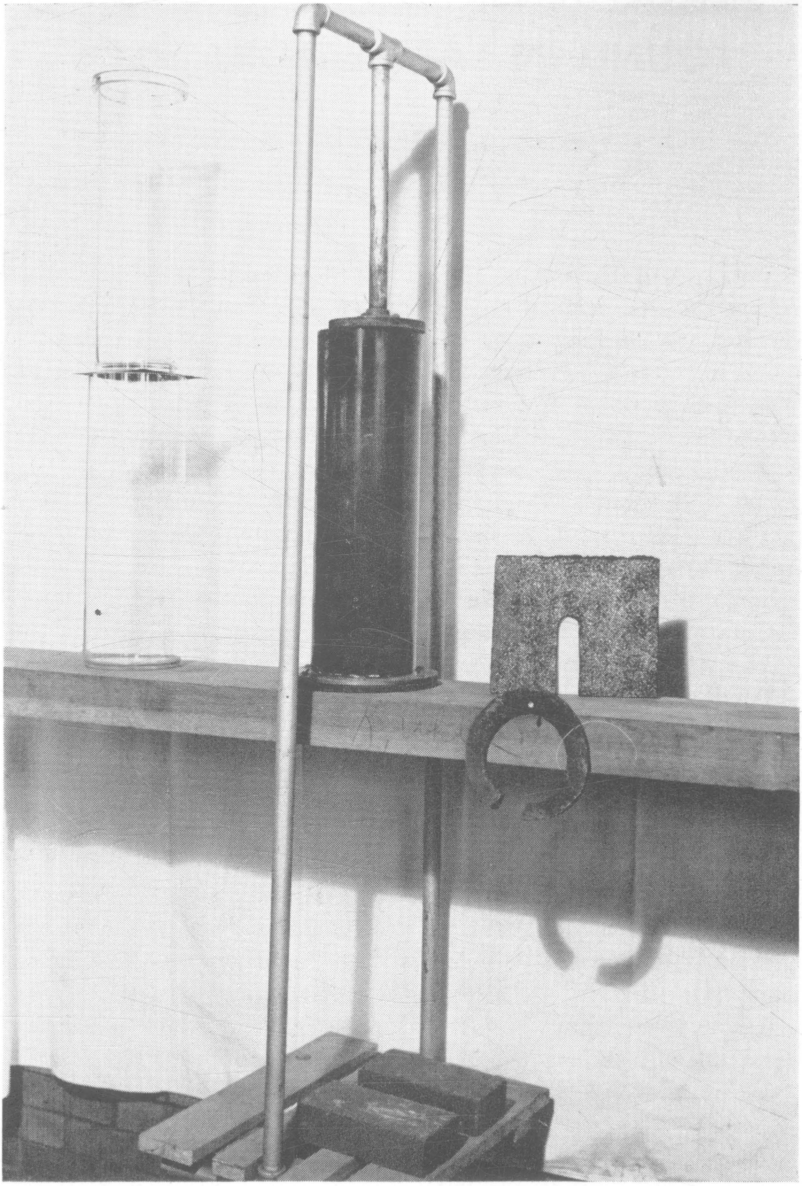

Fig. 1.—This was the first version of the laboratory silo consisting of an 18 inch section of six inch steel pipe. A weight on the platform determined the amount of pressure applied.

as plungers were substituted, while the other parts remained essentially the same. These cylinders were satisfactory at low pressures, but failed under higher pressures.

Later, a cylinder with a glass inside surface and with a flange[4], (Fig. 2), was used and bolted to a plate of similar construction. The joint was sealed by a rubber gasket. The bottom plate was tapped to permit attachment of the fruit jar to collect drainage juices. This silo proved entirely satisfactory and was used for the following experiments.

The internal diameter and cross-sectional area of each silo were determined and recorded in advance of experimental work. Thereafter, measurements of depth gave cubical contents. The material to be ensiled was chopped to the desired fineness and a weighed amount,

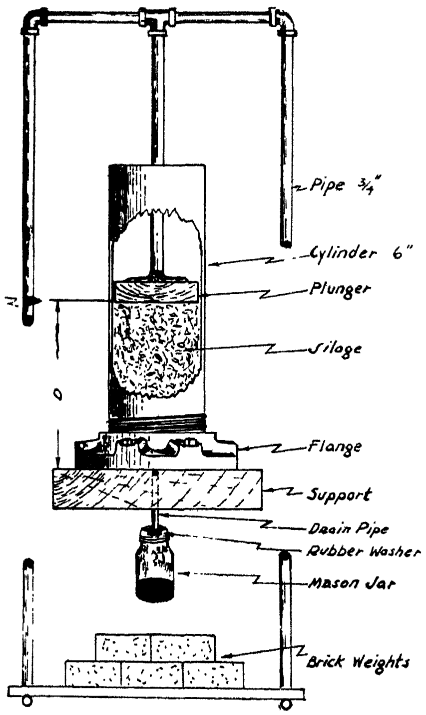

Fig. 2.—This drawing shows the later device used in laboratory tests. A hole in the bottom plate allowed the drainage juices to be trapped. This equipment was used for the experiments described in this circular.

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[4]Supplied through the courtesy of the A. O. Smith Corporation, Milwaukee, Wisconsin.

usually nine pounds was placed in a silo with thorough and as uniform compaction as possible. The frame carrying the plunger and weight platform was then placed in position and the initial depth of material recorded. Additional weights required for the individual experiment were then placed on the hanging platform.

Depth readings were made at regular intervals and accumulated leakage was weighed. Repeated determinations of the specific gravity of seepage juice varied little from 1.03 and this value may be used to convert volume to weight.

At the conclusion of a fermentation period the weights and plunger were removed. The top spoilage and good silage were removed and weighed separately. Dry matter and other determinations were made of the material ensiled and of the silages. In the later experiments the silages were scored on physical condition, color, taste, and odor by several experienced workers.

In preliminary experiments when techniques were being evolved, few silos were available. If leakage ceased at one pressure additional weights were added and the resulting leakage and volume shrinkage were recorded. This stepwise procedure permitted collection of additional data from a single filling of a silo. But as this procedure did not duplicate the conditions which exist in a silo, this practice was abandoned when more silos were available.

RESULTS AND DISCUSSION

Dry-matter Content of Crops: The dry-matter contents of corn and of mixed meadow crops at several characteristic stages of development are shown in Table 1. Legumes before blooming and grasses before heading show about the same dry-matter content as corn in the tassel and silk stage.

Leakage Losses: The silos were filled with corn and meadow crops cut to a small particle size. The dry-matter content of the materials varied over a wide range. Likewise the pressures applied varied from 2 to 16 pounds per square inch as shown in Table 2.

A heavy loss of liquid occurred from materials of 14 to 18 percent dry matter at all pressures. When the dry-matter content was higher no seepage occurred without added pressure. No seepage occurred in the case of either corn or meadow crops when the material contained 32 percent dry matter, even when 16 pounds pressure were applied. Corn which had not reached the late-dough stage or legumes before the full-to-late bloom stage, unless wilted, usually leaked badly. This fact applies in farm silos also. Leakage from this type of material will be pronounced in all farm silos but especially in the taller ones.

Although the materials in the 25 to 30 percent dry-matter group may undergo some leakage in the deepest silo fills, the loss will not be serious, and no loss is likely to occur in the ordinary silo or in the top portion of any silo. The prospects of obtaining high quality silage are also much better at 25 to 30 percent dry matter regardless of treatment.

Silage Densities: Both the stage of growth of the ensiled material and the depth of the silage affect the silage density attained in farm practices. The density in pounds per cubic foot of corn silage at different stages of growth with varying pressures applied in these experimental silos is shown in Table 3. The densities shown at 8 pounds pressure are those most likely to occur in the lower portion of silos of 30 to 36 feet.[5] The densities shown at the two to four pound pressure range are likely to occur in the top third of a silo. Seepage occurs when

TABLE 1.—Effect of Stage of Growth on the Dry-matter Content of Crop

No. of Samples	Type of crop and growth stage	Dry-matter Content	
		Range	Average
		Percent	Percent
	Corn		
14	Tassel and silk stages	14.0—18.0	16.1
13	Early milk stage	16.9—21.0	18.6
8	Late milk stage	20.1—21.6	20.9
9	Dough and glazing stage	25.5—26.0	25.8
2	Grain mature, husk still green	32.0—32.0	32.0
3	Grain mature, husks brown, most of stalk green	38.5—39.5	38.8
	Meadow Crop		
16	Clover, alfalfa or soybeans before bloom; grasses and cereals before heading; older crops grown on wet soil or wet with rain or dew.	13.5—20.0	17.1
19	Clover or alfalfa, early bloom under normal weather and soil conditions; grasses and cereals headed to bloom, soybeans bloom to early seed.	20.5—25.0	22.6
14	Clover or alfalfa, full to late bloom; grasses and cereals, early seed stage; soybeans, seed half or more developed.	25.5—29.5	27.3
10	Alfalfa or clover, late bloom to seed; grasses and cereals, seeds formed; plant still green in appearance.	30.5—43.0	33.4

[5]As shown by the data of C. H. Eckles, O. E. Reed, and J. B. Fitch (1919) Kansas Agricultural Experiment Station Bulletin 222; and J. B. Shepherd and T. E. Woodward (1941) United States Department of Agriculture Circular 603.

TABLE 2.—Pounds Seepage Lost From 9 Pounds of Plant Material of Different Stages of Growth Over a Range of Applied Pressures

Stage of growth as indicated by dry-matter content	Pounds pressure applied per square inch						
	2	4	6	8	10	12	16
Percent	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
				CORN			
14 —18	0.205	0.436	0.904	1.715		2.582	
18.5—22.5		0.013		0.842	0.793		
23 —27		0.147	0.570	0.613		1.254	1.500
27.5—31			0.099	0.429			
32 —39.5				0.0	0 0	0 0	0.0
				MEADOW CROPS			
15.5—18		2.652		2.575			
18.5—22.5		0.921		1.656		2.343	2.791
23 —27		0.159		1.446		2.262	
27.5—31		0.0	0.0	0.262	0.456	0.602	0.633
32 —38.5					0.0	0.0	0.0

No entry signifies no observation.
0.0 indicates an observation but no leakage.

TABLE 3.—Relation of Applied Pressure and Stage of Growth to the Density and Weight of Dry Matter per Cubic Foot of Corn Silage

Growth stage of corn	Dry matter		Pressure per square inch, lbs.			
			2-4	6-8	10-12	14-16
	Percent		Pounds per cubic foot			
Tassel and silk	16.1	Moist silage	43.8	49.8	58.7	
		Dry matter	**7.05**	**7.99**	**9.49**	
Milk or roasting ear	19.4	Moist silage	46.4	51.6	54.6	
		Dry matter	**8.99**	**9.99**	**10.61**	
Dough and glazing	25.8	Moist silage	49.0	51.0	55.0	56.2
		Dry matter	**12.67**	**13.17**	**14.17**	**14.48**
Mature or nearly so	36.1	Moist silage			40.7	46.8
		Dry matter			**14.67**	**16.85**

the density approaches 50 pounds of silage per cubic foot. The same relationships that have been discussed above apply to the data of the meadow crop silages of Table 4. Some of the irregularities apparent in Table 4 are probably the result of the diversity of plant species in the meadow crops ensiled, as the plant species are not equally represented at each of the different stages of growth. The effect of varying the amount of applied pressure on the density of silage and dry-matter density at successive dates during the period when fermentation is occurring is shown in Figure 3.

In a large series of leakage studies the experimental silos and con-

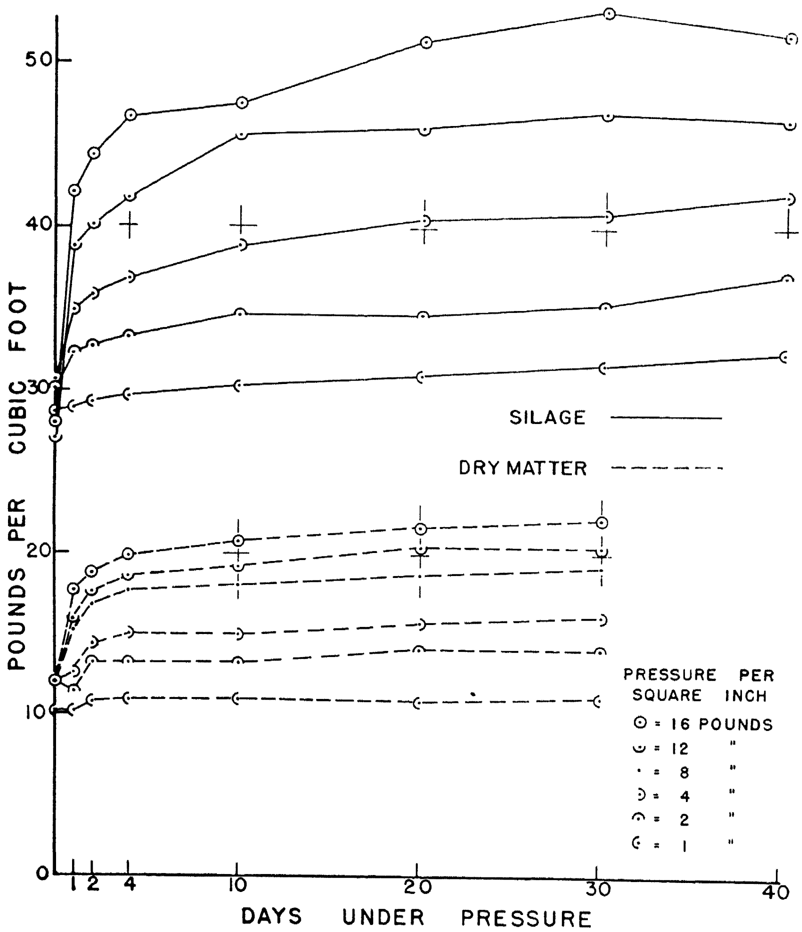

Fig. 3.—This chart indicates the effect of varying the amount pressure applied on the density of silage at successive dates during the fermentation period.

TABLE 4.—Relation of Applied Pressure and Stage of Growth to the Density and the Weight of Dry Matter per Cubic Foot of Meadow Crop Silage

Number of silages studied	Growth stage of crop	Dry-matter			Pounds per pressure per square inch				
		Range	Average		2	4	8	12	16
		Percent	Percent		Pounds per cubic foot				
11	Pre-bloom	15.5—20.0	17.9	Moist silage	41.3	57.8	57.7	60.0	60.5
				Dry-matter	**7.37**	**10.36**	**10.36**	**10.74**	**10.86**
19	Early bloom	20.1—25.0	22.8	Moist silage	55.5	53.6	58.6	57.4	64.7
				Dry-matter	**12.67**	**12.10**	**13.36**	**13.11**	**14.73**
13	Full bloom	25.1—30.0	28.0	Moist silage	49.8	45.0	53.5	57.4	60.9
				Dry-matter	**13.92**	**12.61**	**14.98**	**16.10**	**17.04**
27	Late bloom to seed, or wilted	30.1—54.0	39.0	Moist silage	35.3	39.9	44.3	51.3	50.6
				Dry-matter	**13.73**	**15.54**	**17.29**	**19.41**	**19.72**

tents have been weighed to determine the density prior to leakage and also after leakage began. In a series of 17 such observations where the weighings were made just prior to leakage and shortly thereafter the densities increased from 60.0 pounds per cubic foot before leakage to 66.9 pounds after leakage had progressed.

Fineness of cut is thought to be an important factor affecting the density of silage. Fine, medium and coarse cut corn (32 percent dry matter) and alfalfa (34 percent dry matter) were ensiled separately. The effects of fineness of cut and of the length of time after filling upon the density of silage under one continuous load in these small containers are shown in Figure 4. In the case of both corn and alfalfa the finer cut material settled more rapidly and attained a much greater density. This resulted in more nearly complete exclusion of air and better quality silage. The corn silage reached final densities of 59, 56 and 50 pounds per cubic foot for fine, medium and coarse cut; densities of 60, 49 and 41 were attained in the case of alfalfa. If the amount of top spoilage was counted as 100 on the fine cut it was 160 on the medium cut silage and 240 on the coarse cut.

Dry-matter Density in the Laboratory Silos: The effects of applied pressure and stage of growth on the weight of dry matter per cubic foot in both corn and meadow crop silage may be seen in Tables 3 and 4. When corn is cut in the dough or glazing stage the dry-matter content of settled silage is from 70 to 80 percent greater for the same weight of crop than when cut in the tassel and silk stage. This relation in the

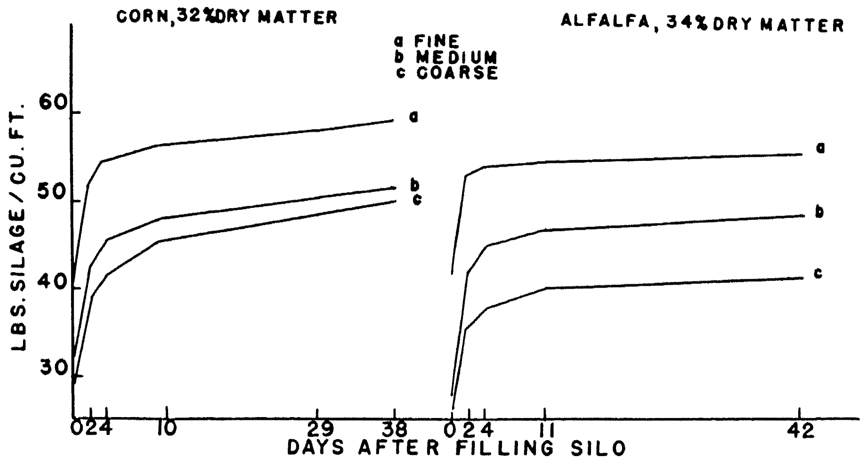

Fig. 4.—The effect of fineness of cut and the length of time after filling upon the density of silage in the small containers is shown here.

silage holds true regardless of the amount of pressure applied. The same relationship is true in case of greater age, or wilting, of meadow crops.

In this series, the weight of dry matter per cubic foot increased with each increase in pressure; likewise, the dry-matter density increased with fineness of cut.

Even when the crop is so old or dry that no leakage occurs, the dry-matter density increases by about 50 percent in 30 days in the silo as seen in Table 5. The percentage increase in dry-matter density is progressively lower in silage from materials of greater dry-matter content; in other words, as is well known, drier materials do not settle as much after ensiling. Their mechanical strength is one reason; they do not lose volume by drainage.

The effects of applied pressure for different periods after filling the silos on the dry-matter density may be seen in Figure 3. When only one pound of pressure was applied there was scarcely one pound of increase in dry-matter density in 30 days; with 16 pounds of pressure applied there was a 10-pound increase of dry-matter density. With eight pounds of pressure applied the dry-matter density closely approached the observed maximum.

With the greater amounts of applied pressure the dry-matter density increased rapidly in the first few days after ensiling. The relationship between the dry-matter densities at different rates of applied pressure is more constant than is that of pounds of moist silage per cubic foot.

The increased dry-matter density which accompanied the increased applied pressure goes with the exclusion of air and development of greater acidity. This is true with respect both to titratable acidity and pH; the titratable acidity increased with increases in applied pressure while the pH values decreased. These relationships held true over a

TABLE 5.—Relation of the Dry-matter Content of Meadow Crop and Time of Settling to the Pounds of Dry Matter per Cubic Foot of Silage

Dry-matter	Initial			Time in Days			
Percentage	0	1	2	4	10	20	30
Below 30	8.17	9.42	9.78	10.93	11.63	12.23	12.43
30.1—35	10.78	13.45	14.04	14.63	15.49	16.95	17.03
35.1—40	10.69	13.57	14.09	14.63	15.59	16.35	16.76
40.1—45	11.66	14.05	14.45	14.77	15.30	15.66	15.78
45.1—50	13 39	15.23	16.31	16.69	17.29	17 87	18.19
Above 50	16 08	18 03	19.20	19.47	20.04	20 50	20.89

range of 20-to-40 percent dry-matter content of ensiled material. Cutting to a small particle size resulted in better exclusion of air and therefore in development of greater acidity in these silages.

Increases of applied pressure resulted in marked decreases in the amount of top spoilage on all crops ensiled—alfalfa, corn and timothy.

Intangible Losses: The losses not accounted for as top spoilage and leakage from silages are known collectively as "intangible losses". Bender and associates of New Jersey, stated that these losses average 8 to 10 percent, and others estimate them to be as high as 15 percent. In this series, the experimental silos were covered with overlapping sheets of waterproof felt paper (Fig. 2) which were weighted down to reduce entrance of air. The only surface that was exposed to the air in the space between the plunger and the waterproof lid was the very narrow ring of moist material between the plunger and the silo wall. When room air was entrapped in this space at filling time the air was only partially saturated with moisture and carbon dioxide. Evaporation of both from the silage into the air space continued until the end of the experiment. In a few cases the intangible losses were reduced to less than two percent by placing a moist cloth on the plunger, after the covers were put in place. Table 6 shows the range and average losses sustained with a variety of ensiled materials. These results indicate conclusively that the intangible losses from loss of gasses of fermentation can be much lower than formerly believed, on the basis of dry-matter measurements made in the conventional way.

On a series of 68 samples the use of the toluene method for dry-matter determinations rather than the oven drying method showed an average difference of two percent more dry matter in the moist samples. On a dry basis the difference would be from three to five times as great. The oven drying procedure is at fault because volatile materials other than water are driven off and the difference between original and oven-dry weight calculated **as water.**

DISCUSSION

That the silage in large silos is usually superior in quality to that in small silos is recognized. Silage near the top is usable and improves until a point is reached where the silage usually ceases to improve. With smaller experimental silos the problem is progressively more acute.

The laboratory silos used for these experiments have proved useful in the following respects:

1. Small amounts of material of uniform condition and composition will fill the entire series of 18 laboratory silos. Thus the effect of a single factor may be studied in triplicate at six levels.

TABLE 6.—Intangible Losses in Silage Making

Sample No.	Material Studied	Number of Obser-vations	Length of Period	Total Weight Loss Maxi-mum	Total Weight Loss Mini-mum	Total Weight Loss Aver-age
			Days	Percent	Percent	Percent
432	Grass and legume mixture	12	20	5.1	1.9	3.7
434	Grass and legume mixture	13	28	9.6	0.3	3.4
435	Alfalfa	14	32	13.3	2.0	4.5†
441	Alfalfa	8	42	4.5	0.9	2.4
442	Corn	12	38	7.3	1.0	3.4
451	Timothy	14	46	11.3	2.4	5.0*
452	Grass and legume mixture	12	33	9.3	1.2	3.1
453	Grass and legume mixture	12	40	25.6	3.3	9.3†
461	Grass and legume mixture	17	34	3.1	1.7	2.4
462	Grass and legume mixture	18	40	2.4	1.1	2.0
463	Corn	18	31	4.0	1.0	2.2
464	Alfalfa	18	47	6.5	0.7	3.3
Weighted Average						3.6
	GLASS SILOS ONLY					
432	Grass and legume mixture	6	20	3.2	1.9	2.5
434	Grass and legume mixture	6	28	2.1	0.3	1.3
441	Alfalfa	6	42	2.7	0.9	1.9
442	Corn	6	38	1.9	1.1	1.4
451	Timothy	6	46	2.8	2.4	2.6
452	Grass and legume mixture	6	33	2.3	1.2	1.7
Weighted Average						1.9

*The experimental silos in this series remained uncovered. Hence a greater loss by evaporation.

†Conducted in a steam heated room. Humidity near zero. Covering poor.

2. The contents of an entire silo are easily mixed for sampling.
3. A series may be filled without the error of differences in stage of growth or changing dry-matter content of the crop.
4. This whole series may be opened and data obtained on the same day.
5. Daily or frequent weighings and depth measurements may be easily made to determine density, seepage and intangible losses.
6. The laboratory silos contain sufficient material for chemical and bacteriological analyses, for judging and for limited tests of relative palatability.
7. The silages produced in these laboratory silos closely approximate in quality those produced in farm size silos.

Several seasons' use of these silos has made one objection evident. The temperature of fermentation is almost exactly that of the room in which the silos stand. Any objection to this condition is largely overcome by keeping the silos in an unheated basement room out of the sun, and at fairly constant temperature.

The data in Figure 3 indicate that density difference between corn and alfalfa silages is not as large as often believed. Meadow crops are often ensiled with a higher moisture content than corn. Adequate wilting of the immature meadow crops will avoid pressures that may damage the silo.

The data on the effects of applied pressure and fineness of cut in these small silos agree with impressions from practical experience. From them it could be recommended that the bottom part of the silo be filled with material of higher dry-matter content (wilted if necessary) and not too finely cut as fineness of cut increases seepage and power costs. The crop in the upper third of the silo may be finely cut and capped with material of high moisture content.

The "intangible losses" or those other than top spoilage and leakage have been reduced to less than two percent in several cases and average about three percent, compared with from 8 to 15 percent as reported by various workers. Loss of gases of fermentation was found to be less than two percent. The differences between the losses reported here and those commonly reported must be largely losses by evaporation. When silage is fed from a farm silo a fresh moist surface is exposed daily or twice daily and the evaporation loss may be great. When there is evaporation of moisture from the silo wall this loss increases, and with walls permeable to moisture vapor this loss may become important; in some silos it does.

SUMMARY

A laboratory-size silo of nine pounds capacity is described. As 18 silos may be filled with less than 200 pounds of material during one day from material of uniform composition, good techniques of study may be developed. A series of observations may be made on one experimental factor with other factors kept constant. Sufficient silage is produced to permit chemical and bacteriological examinations and for judging of odors and physical characteristics. The laboratory silos are inexpensive to operate and they produce a silage that closely approximates in quality that from farm silos.

The dry matter of the ensiled crop must exceed 30 percent to avoid leakage. Juice loss from immature crops may contain as high as 10 percent of the dry matter ensiled.

Results with these experimental silos suggest that farmers may save power and expense by cutting coarsely the materials which contain more than 30 percent dry matter, to go into the lower two-thirds of the silo. Dry materials do not pack tightly even though finely cut. For the upper third the material should be moist and cut reasonably fine to give better exclusion of air, more favorable fermentation and consequently an increased acidity.

In silages from wet or from dry material the dry matter per cubic foot of settled silage varies less than the weight per cubic foot of moist silage. This comparative uniformity in dry-matter content is helpful in practical feeding of cattle.

When the moisture content of the ensiled material, whether corn or meadow crop, is high fine cutting is detrimental, resulting in too dense packing, a cold silage, and too much juice loss. Fine cutting of moist crops reduces top spoilage if there is also satisfactory mechanical compaction along with the reasonably fine cut (½″ to ¾″).

With the laboratory silos described here, the unaccounted losses have been reduced to an average of three percent, and in several individual silos to less than two percent. The losses by escaping gases are shown to be less than two percent and lower than former studies indicated.